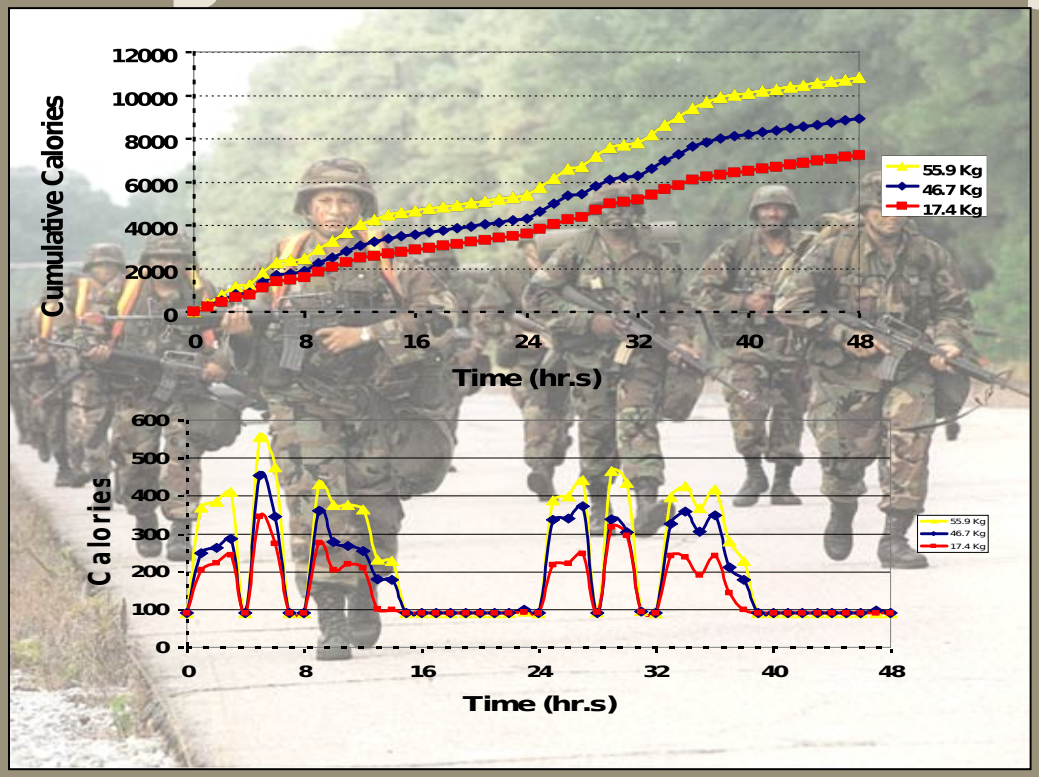
Warfighter Performance Modeling: Metabolic Fatigue



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Performance Modeling

Objectives/Applications:

- Demonstrate the psycho-physiological costs & benefits of novel products or doctrine.
- Reduce overall program risk through Simulation Based Acquisition.

Approach:

- Develop model(s) to estimate the effects of operational stress on psycho/physiological state.
- Integrate these models into individual combatant models (e.g., IWARS)

Limitations:

- Applicability limited by development stage of psycho-physiological models

Metabolic Fatigue

Definition:

- **Failure to maintain work level due to under-nutrition, carbohydrate depletion or slowing of metabolic machinery.**

Cause:

- **Depletion of usable energy (ATP) due to:**
  - Rates of ATP production not meeting rates of ATP utilization due to:
    - 1. Depletion of key metabolic fuels
    - 2. Slowed biochemical reaction rates
    - 3. Extremely high levels of physical activity

Key Metabolic Fuels

Very Short Term (seconds):

- **Phosphocreatine**
- **Stored ATP**
- **Muscle Glycogen**

Prolonged (hours):

- **Carbohydrates (Muscle Glycogen, Blood Glucose, Liver Glycogen)**
- **Fatty Acids (from adipose and muscle tissue)**

Extended Duration (days):

- **Carbohydrates (very limited availability)**
- **Fatty Acids (from adipose tissue)**
- **Ketones**
- **Proteins**

Dynamic Nutrition Model (DYNUMO)

Ultimate Objective:

- Model the effects of macronutrient intake and physical activity on metabolic fuel status during military operations.

General Approach:

- Develop algorithms based on known physiology and biochemistry
- Test using available data

Iterative Approach:

- Currently limited to “prolonged” (several minutes to several hours), steady state activity, with and without macronutrient intake.

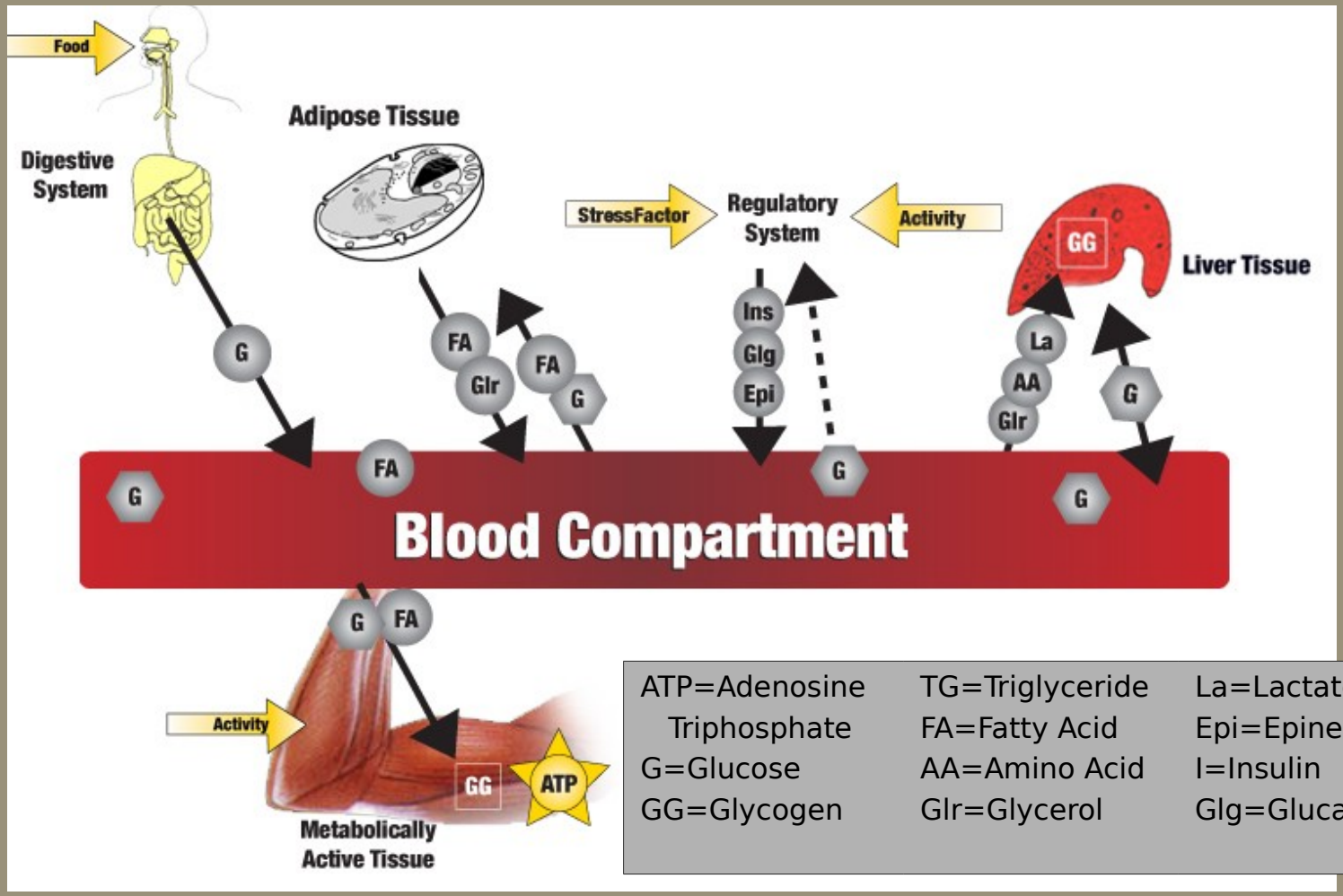
DYNUMO Inputs & Outputs

FOOD (CHO, Fat & Protein)
ACTIVITY (Metabolic Rate)
STRESS (Epinephrine) FACTOR
SUBJECT CHARACTERISTICS
STARTING CONDITIONS (e.g., Plasma Glucose)
METABOLIC FUEL AMOUNTS (e.g., Muscle Glycogen)
METABOLIC FUEL STATUS
METABOLIC FUEL UTILIZATION RATES

Limiting Metabolic Fuels for Performance

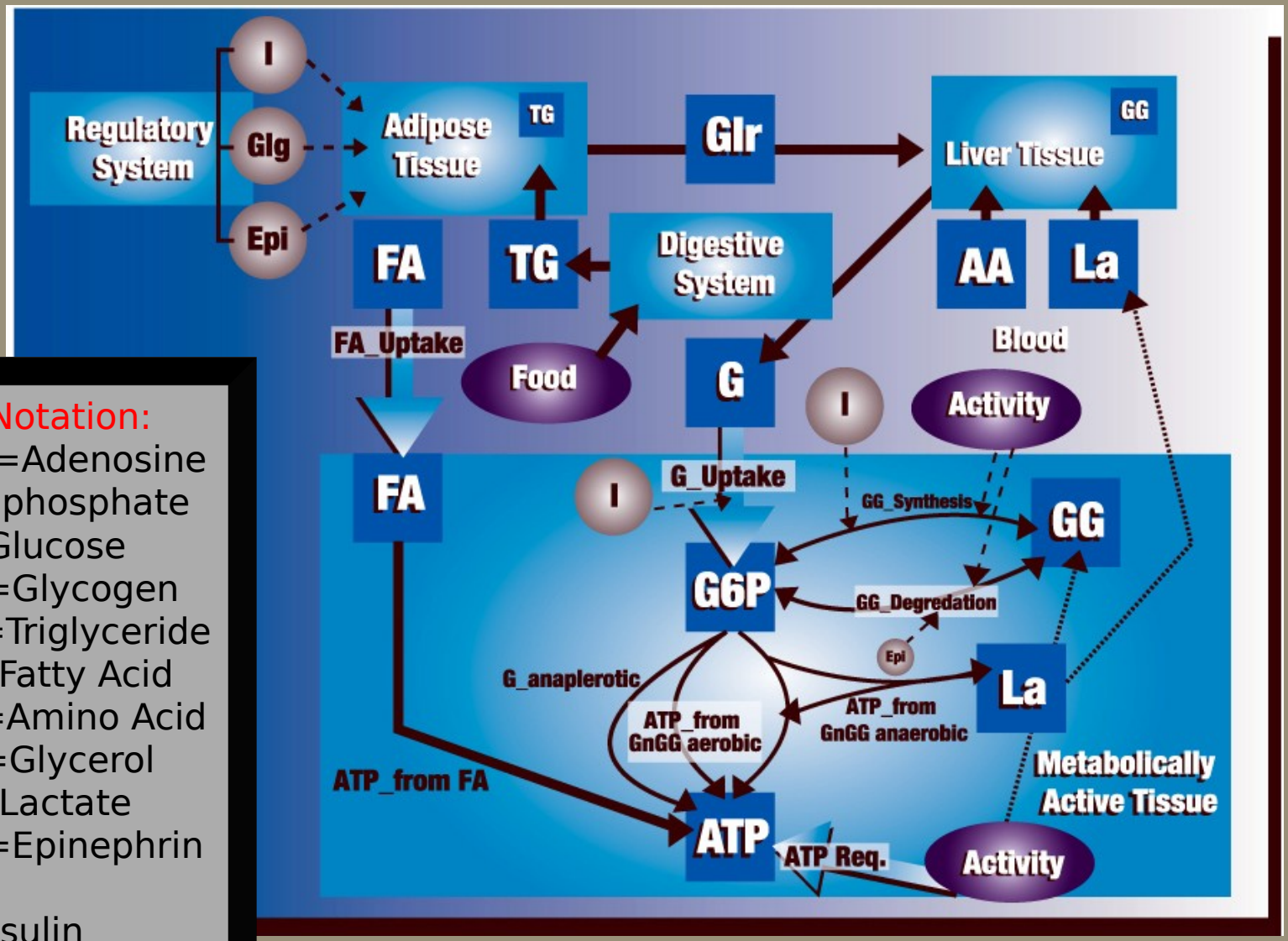
- **Muscle glycogen** is the primary limiting factor for physical performance (under steady state conditions).
- **Blood glucose** is the primary limiting factor for cognitive performance and affects physical performance in some cases.
- **Liver glycogen** is a reservoir for blood glucose.
- **Fatty Acid** utilization helps determine glycogen and glucose utilization in muscle while, at the whole-body level, glucose availability helps determine fatty acid release from adipose tissue.

Model Schematic



ATP=Adenosine Triphosphate	TG=Triglyceride	La=Lactate
G=Glucose	FA=Fatty Acid	Epi=Epinephrine
GG=Glycogen	AA=Amino Acid	I=Insulin
	Glr=Glycerol	Glg=Glucagon

Metabolic Processes



Notation:

ATP=Adenosine Triphosphate
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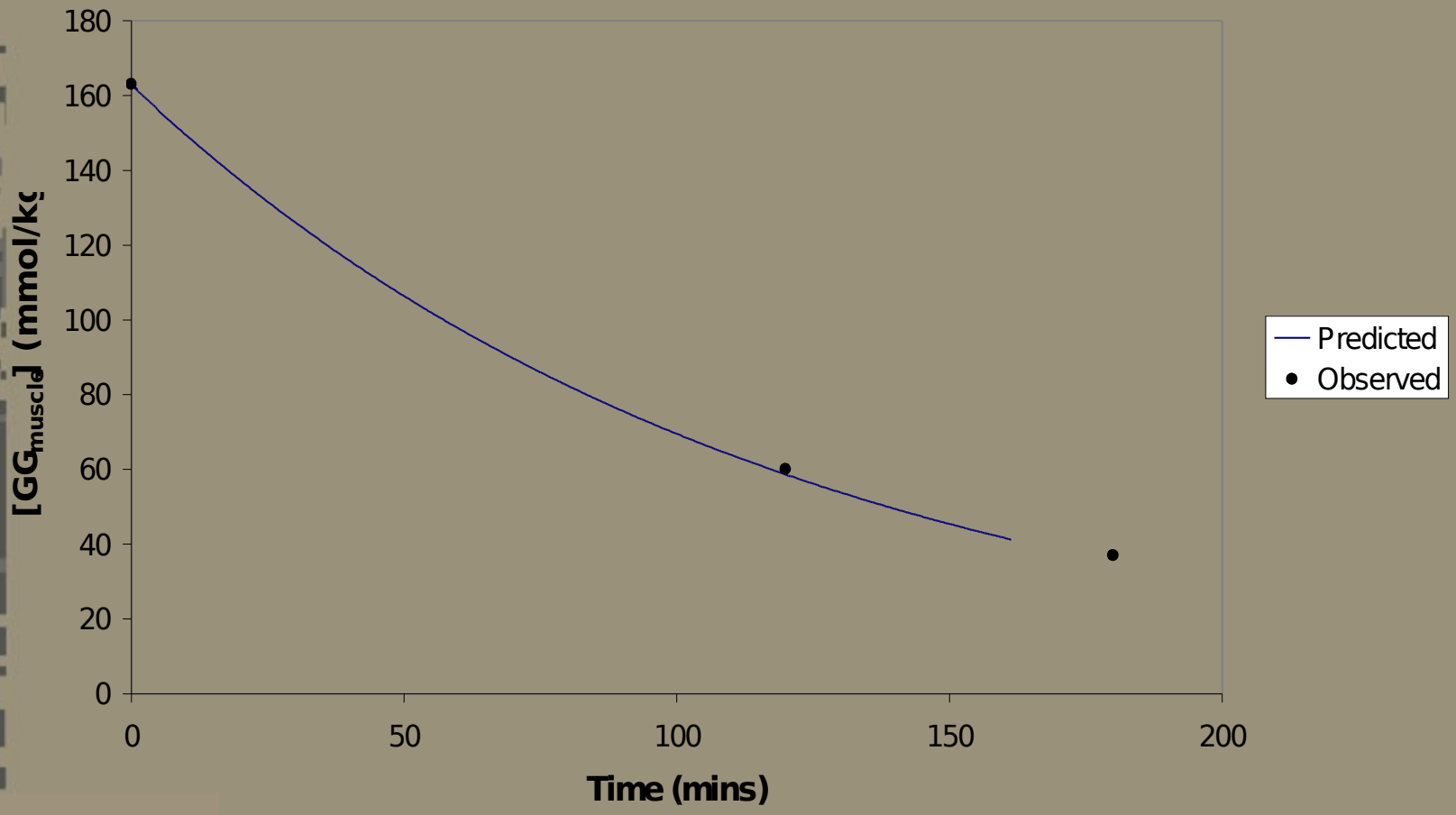
Glg=Glucagon

Testing
(Simulation of Coyle et al., 1986)



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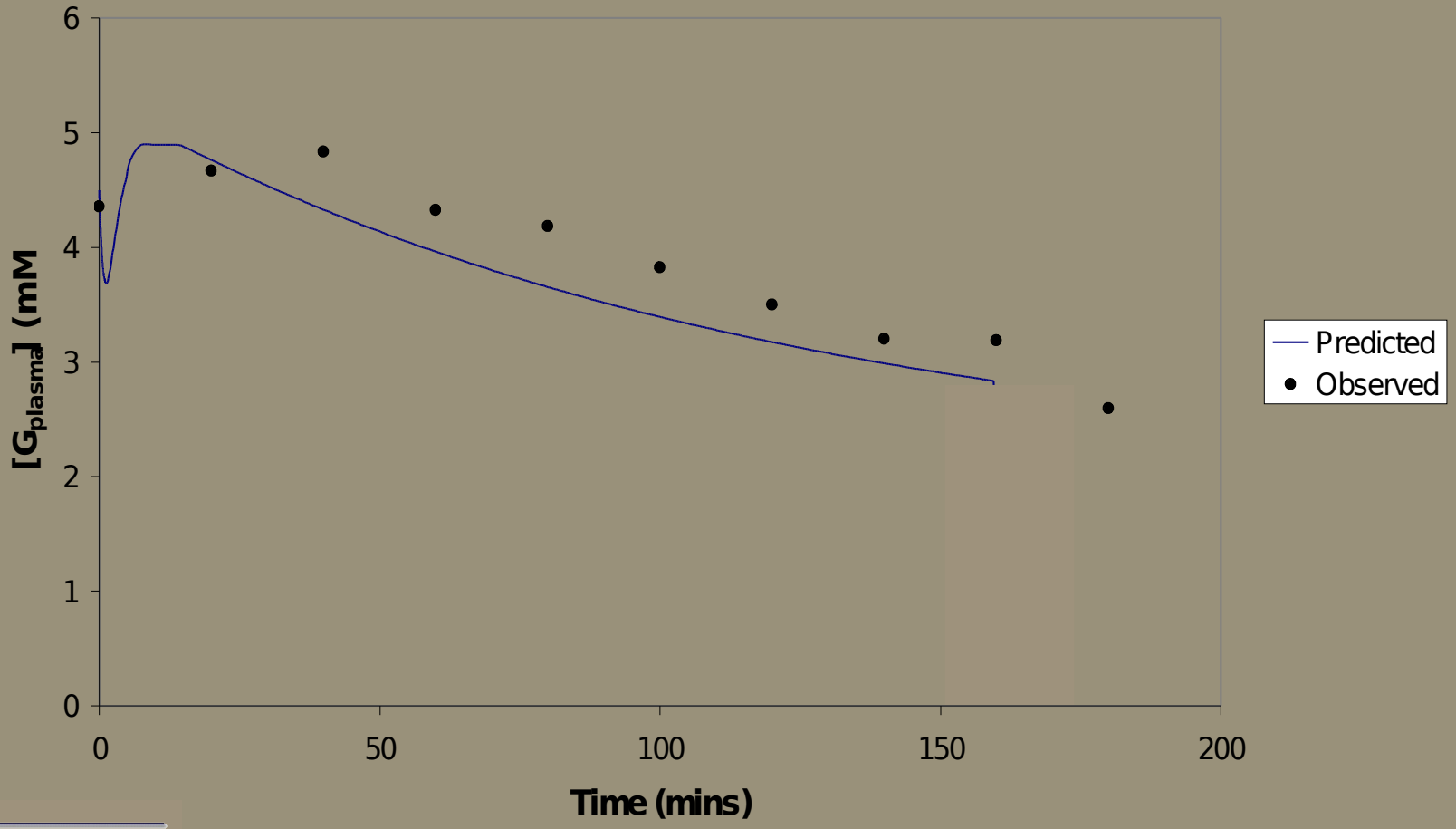
Testing
(Simulation of Coyle et al., 1986)



Flow
Hydration Level
10%
8
6
4
2
0
-2
-4
-6
-8
-10%
-0.07%
Flow
Liver Glycogen
100
80
60
40
20
0
54.53g/Kg
Flow
FAT
Total Body Weight
160 lbs
Percent Fat
14%
Flow
Plasma Glucose
150
130
110
90
70
50
30
77.67 g/dl
Flow
Muscle Glycogen
50
40
30
20
10
0
29.09g/Kg
% VO2 Max
40
50
60
30
70
20
80
10
90
0
100
70
Work Intensity
Core Temperature
Celsius
Fahrenheit
40
39.5
39
38.5
38
37.5
98
37
97.24
37.01 C
Activity Control
Activity
Fast Forced March
Rate
1.980
m/s
Load
49
kg
External
Grade
10
%
Amb Temp
20
Degrees C
Humidity
40
%
Input
Flow
Input
0
g
Carbohydrates
0
g
Fat
0
g
Protein
0
g
Water
0
mL
Flow
Elapsed Time
00:01:53
Hours:Minutes:Seconds
Aprox Time to Exhaustion
00259
Hours:Minutes
Time Remaining
03:28:07
Hours:Minutes:Seconds

DYNUMO
Collaborations & Support

- Modeling and Analysis Team, U.S. Army Soldier Systems Center, Natick, MA. POC: Mr Paul Short (paul.short@natick.army.mil, 508-233-4256)
- Combat Feeding Program, U.S. Army Soldier Systems Center, Natick, MA
- Nutrition Division, U.S. Army Research Institute of Environmental Medicine, Natick, MA
- U.S. Department of Defense Combat Feeding, Research and Engineering Program

Summary

- **Models of individual combatant behavior may be used for mission planning & analysis, soldier system development & analysis, and simulation-based acquisition.**
- **DYNUMO may be used within such models to estimate the effects of warfighter activity and nutrient intake on metabolic aspects of fatigue. DYNUMO is currently capable of estimating metabolic status and glucose requirements during prolonged, steady-state physical activity, with and without macronutrient intake.**